# Zeebrugge Model

*wave runup under simulated prototype storms (II) and the influence on wave runup introducing a current*

Jensen, Morten S.; Frigaard, Peter

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Jensen, Morten Sand; Frigaard, Peter Bak

COMMISSION
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MAST III

THE OPTIMISATION OF
CREST LEVEL DESIGN OF
SLOPING COASTAL STRUCTURES
THROUGH PROTOTYPE
MONITORING AND MODELLING

# OPTICREST

MAS3-CT97-0116

*FINAL EDITION*

# Zeebrugge model:

## - Wave runup under simulated prototype storms (II)

## - The influence on wave run-up introducing a current

Morten Sand Jensen
Peter Frigaard

September 2000

REPORT

**HYDRAULICS & COASTAL ENGINEERING LABORATORY**
AALBORG UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING
SOHNGAARDSHOLMSVEJ 57 DK-9000 AALBORG DENMARK
TELEPHONE +45 96 35 80 80 TELEFAX +45 98 14 25 55

HYDRAULICS & COASTAL ENGINEERING LABORATORY
AALBORG UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING
SOHNGAARDSHOLMSVEJ 57 DK-9000 AALBORG DENMARK
TELEPHONE +45 98 35 80 80 TELEFAX +45 98 14 25 55

# 1 Introduction

In the following, results from model tests with Zeebrugge breakwater are presented. The objective with these tests is partly to investigate the influence on wave run-up due to a changing waterlevel during a storm. Finally, the influence on wave run-up due to an introduced longshore current is investigated.

All model tests are performed in august year 2000 at the 3D wave facilities at the Hydraulics and Coastal Engineering Laboratory, Aalborg University (AAU).

Layout of the scale model in 1:40 and the details are given in /1/. Figure 1 shows the model of Zeebrugge Breakwater during a test.

Figure 1: *A picture of a run-up event in the laboratory.*

# 2 Simulation of prototype storms

The storm events recorded at Zeebrugge Breakwater the 6-7 November 1999 are analyzed following the specifications given in /2/.

Each storm are divided into five sessions to simulate the changing waterlevel throughout the storm. This results in a total of 10 storm events. The reproduction of the spectra were performed with the correct waterdepth and repeated until an acceptable correspondence between the prototype spectrum and model spectrum was obtained.

Following table describes the storm sessions reproduced in the basin. Results from the model tests are given in prototype values. The target waterlevel (TWL) or still-waterlevel simulated is taken as the mean waterlevel (MWL) measured at the site of the prototype.

Figure 1 to 4 shows a comparison between the spectra.

| PROTOTYPE | | | | MODEL | | | | |
|---|---|---|---|---|---|---|---|---|
| Storm no./time | $H_{mo}$[m] | $T_p$[sec.] | $T_{01}$[sec.] | $H_{mo}$[m] | $T_p$[sec.] | $T_{01}$[sec.] | $H_s$[m] | $T_m$[sec.] |
| 8/9h30-10h30 | 2.31 | 7.2 | 5.6 | 2.43 | 7.2 | 6.0 | 2.35 | 6.1 |
| 8/10h30-11h30 | 2.75 | 7.2 | 5.9 | 2.76 | 7.2 | 6.1 | 2.70 | 6.1 |
| 8/11h30-13h30 | 2.99 | 7.2 | 6.3 | 3.12 | 8.0 | 6.6 | 3.10 | 6.7 |
| 8/13h30-14h30 | 2.90 | 7.2 | 6.2 | 2.88 | 7.2 | 6.7 | 2.82 | 6.6 |
| 8/14h30-15h30 | 2.49 | 7.2 | 6.1 | 2.38 | 7.2 | 6.3 | 2.37 | 6.5 |
| 9/21h45-22h45 | 2.49 | 8.9 | 6.0 | 2.42 | 7.2 | 6.2 | 2.42 | 6.2 |
| 9/22h45-23h45 | 2.60 | 7.2 | 6.1 | 2.52 | 7.2 | 6.4 | 2.44 | 6.4 |
| 9/23h45-01h45 | 2.59 | 7.2 | 6.1 | 2.61 | 8.9 | 6.4 | 2.51 | 6.4 |
| 9/01h45-02h45 | 2.54 | 8.9 | 6.1 | 2.40 | 8.9 | 6.4 | 2.35 | 6.1 |
| 9/02h45-03h45 | 2.14 | 8.9 | 5.7 | 2.08 | 8.0 | 5.9 | 2.05 | 5.9 |

These wave characteristics are measured at the position of Waverider 1. In total 79 tests were performed until acceptable correspondence with the spectra of the 10 storm events were obtained. Later in this report the results from these tests will be presented.

## 2.1 Presentation of run-up results

The stepgauge yielded almost identical run-up values from the "Sum" and "Max" signal. In the following the results are based on the "Sum" signal. The run-up is related to the MWL as described in /1/. It is noted that the corrections due to relating the run-up to the MWL was no more than 0.2 m in prototype value. In the following table the run-up results for 2 % exceedence probability are given. Run-up and run-down results at other characteristic levels of exceedence probabilities are given in the end of this report.

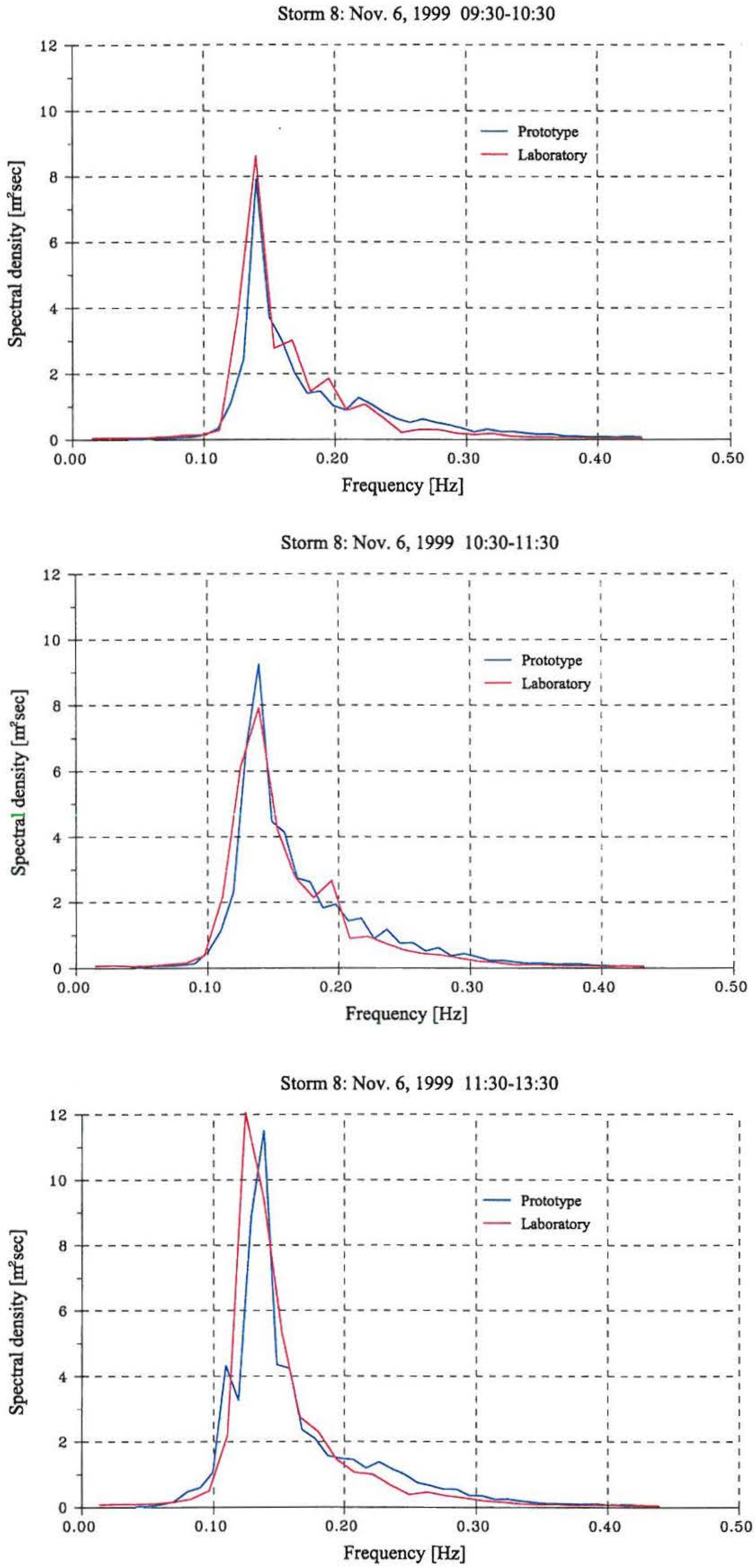



Figure 2: *Simulated spectrum and prototype spectrum for storm 8 - 09h30-13h30.*

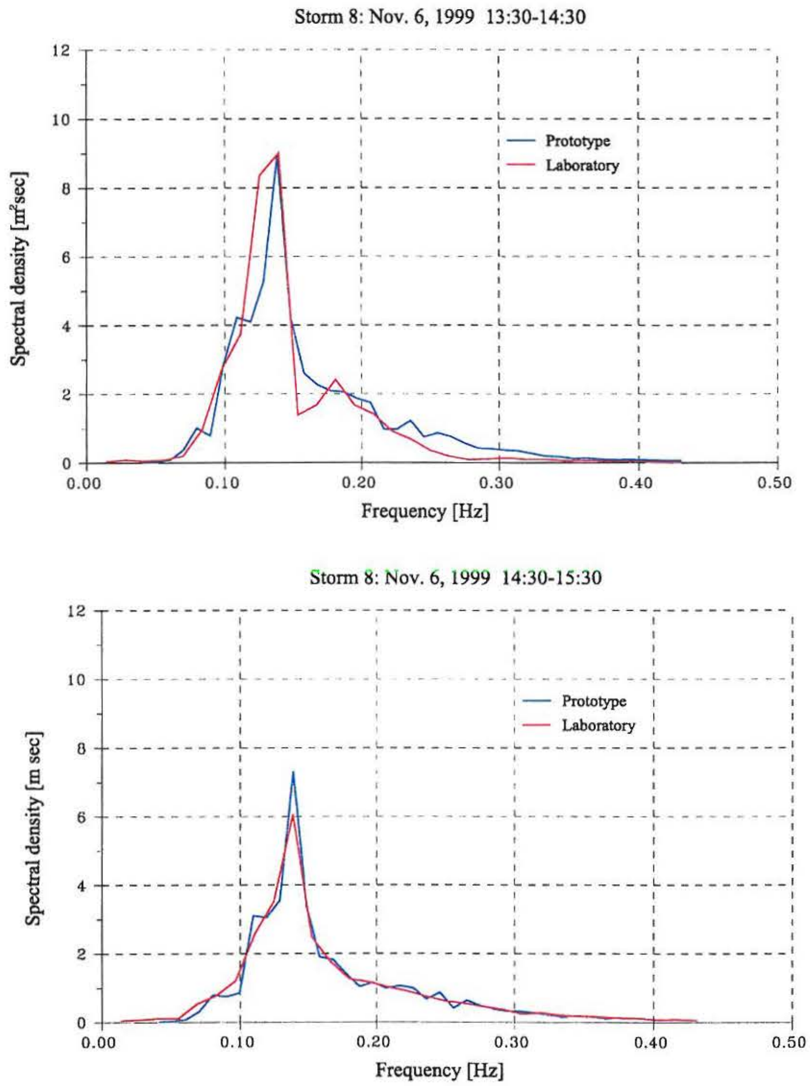



Figure 3: *Simulated spectrum and prototype spectrum for storm 8 - 13h30-15h30.*

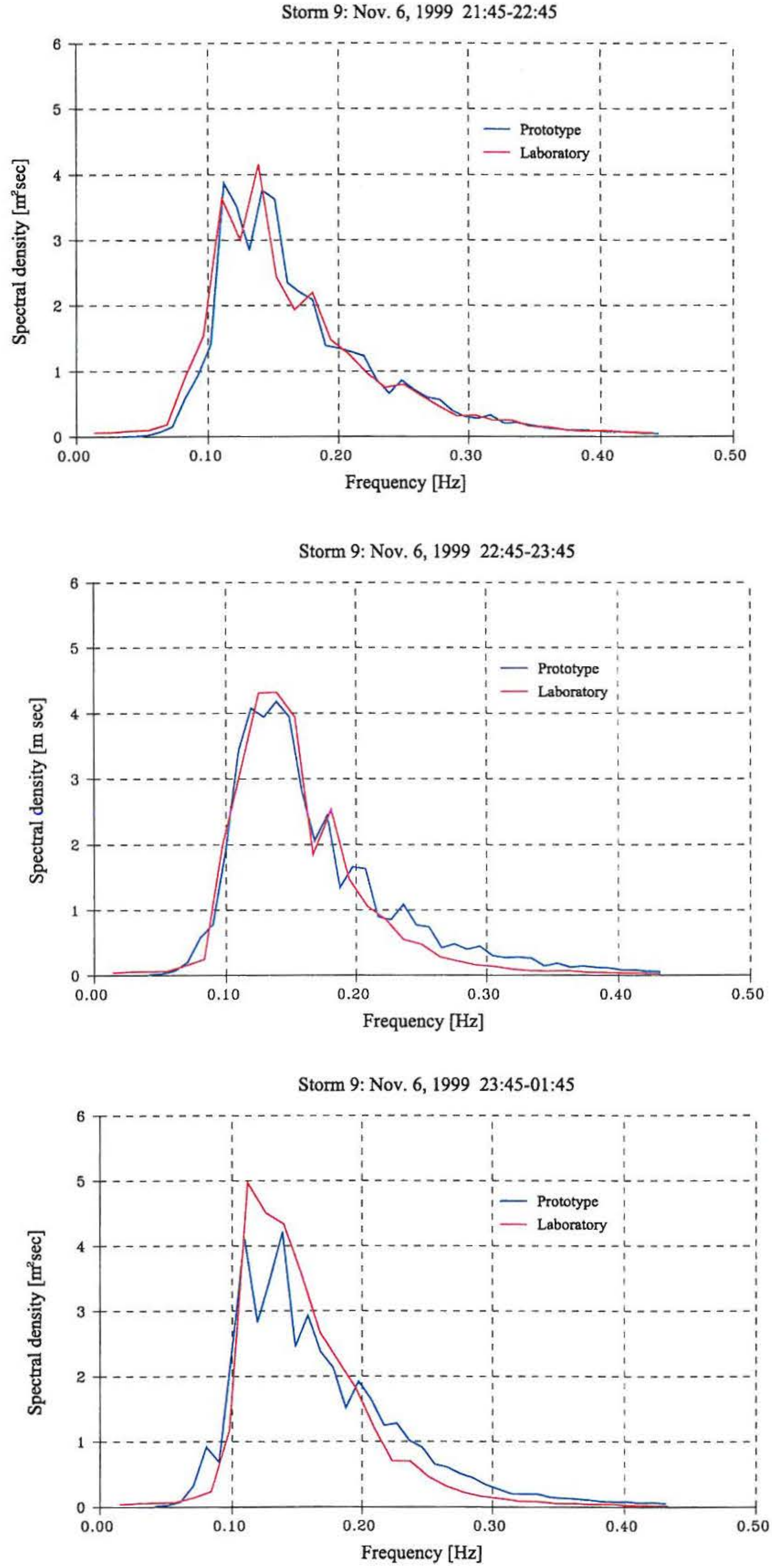
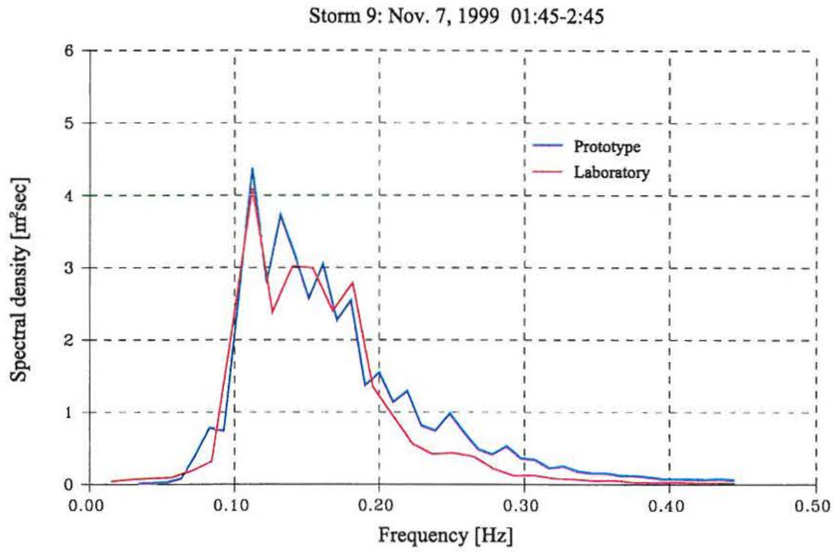



Figure 4: *Simulated spectrum and prototype spectrum for storm 9 - 21h45-01h45.*



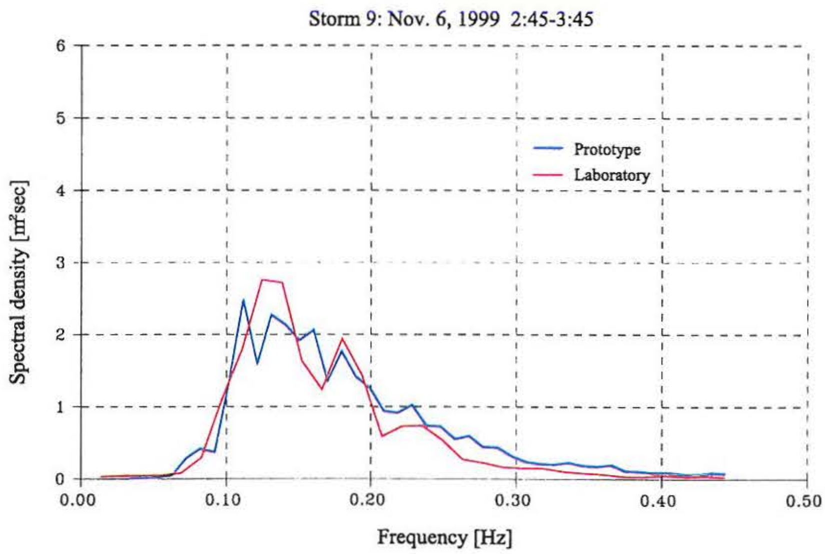




Figure 5: *Simulated spectrum and prototype spectrum for storm 9 - 01h45-03h45.*

| Storm no./time | TWL [m] | $Ru_{ru,2\%}$[m] | $Ru_{ru,2\%}/\ H_{mo}$ [-] |
|---|---|---|---|
| 8/9h30-10h30 | 3.45 | 4.13 | 1.70 |
| 8/10h30-11h30 | 4.53 | 4.14 | 1.50 |
| 8/11h30-13h30 | 5.28 | 4.24 | 1.36 |
| 8/13h30-14h30 | 5.01 | 4.15 | 1.44 |
| 8/14h30-15h30 | 4.28 | 3.93 | 1.65 |
| 9/21h45-22h45 | 3.26 | 4.11 | 1.70 |
| 9/22h45-23h45 | 4.16 | 4.23 | 1.68 |
| 9/23h45-01h45 | 5.11 | 63.34 | 1.28 |
| 9/01h45-02h45 | 4.71 | 3.53 | 1.47 |
| 9/02h45-03h45 | 3.89 | 3.49 | 1.68 |

The Hydraulic Laboratory in Aalborg and Flanders Hydraulic (FCFH) have both simulated the prototype storms 8 and 9. The model at FCFH was made in 1:30. Figure 6 shows the model results for 2% wave run-up compared with the prototype measurements.

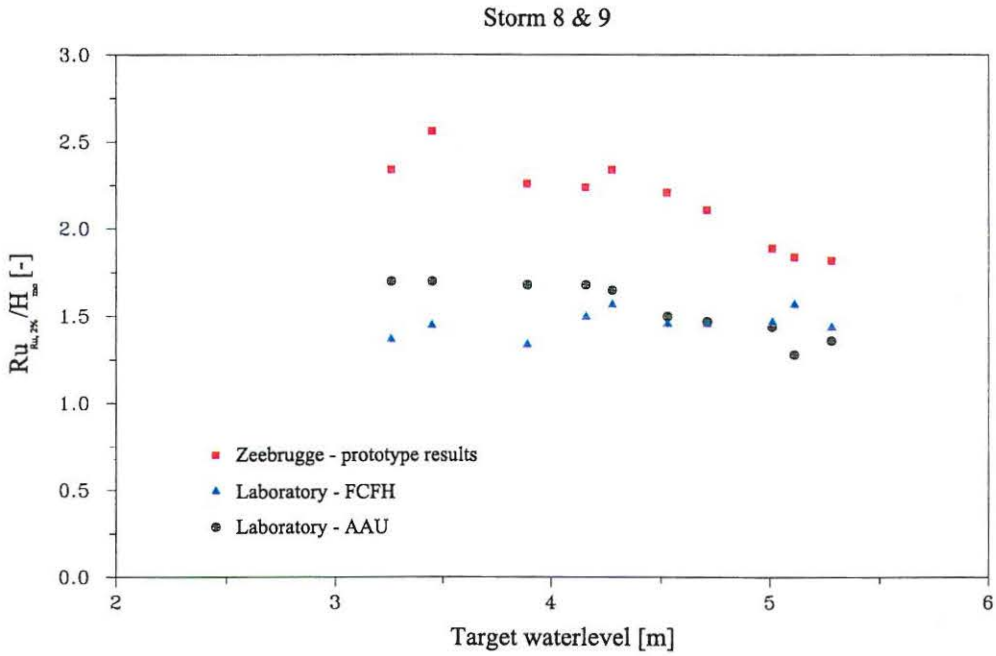



Figure 6: *Relative run-up results measured in laboratory and in prototype.*

It is observed that the laboratory tests at AAU and FCFH yields results at the same level of relative run-up. The prototype values are significant larger than the results from the models. The tendency of larger relative run-up for lesser waterdepth is seen in the model from AAU and in the prototype results.

It should be noted that the correspondence between prototype tests and model test is best in the range of a relatively high target waterlevel.

## 2.2 Comparison to former tests at AAU

Schlutter et al. 1999 reproduced the storms 1 to 5 at the peak event in the laboratory at AAU. The conclusion was that these run-up measurements came very close to the run-up results done at Zeebrugge. A conclusion which can not be made from figure 6.

The model was originally build in march 2000 and not rebuild prior to these current tests. Differences could be expected due to small changes in the breakwater geometry or change of placement of the rubble mound units in the breakwater. In order to validate the tests performed under this subtask the prototype storm recorded the 7 February 1999 is reproduced.

Figure 7 shows the spectrum simulated in the laboratory compared to the spectrum of the prototype storm of the 7 February 1999. In total 8 tests were simulated before an acceptable spectra and $H_{mo}$ was obtained.

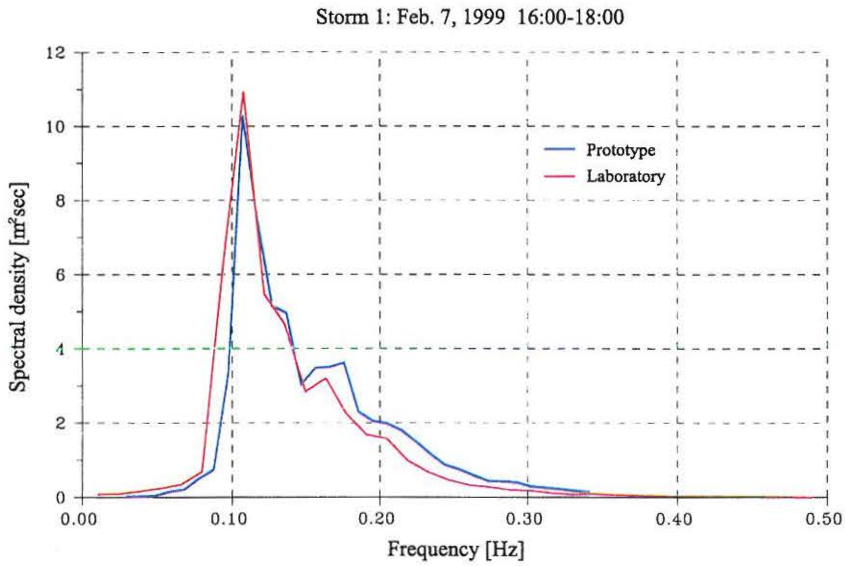



Figure 7: *The reproduced spectrum of the peak storm event 7 February, 1999 16h00-18h00.*

A comparison of the relative run-up plotted against $H_{mo}$, measured at the position of Waverider I, is seen in figure 8.

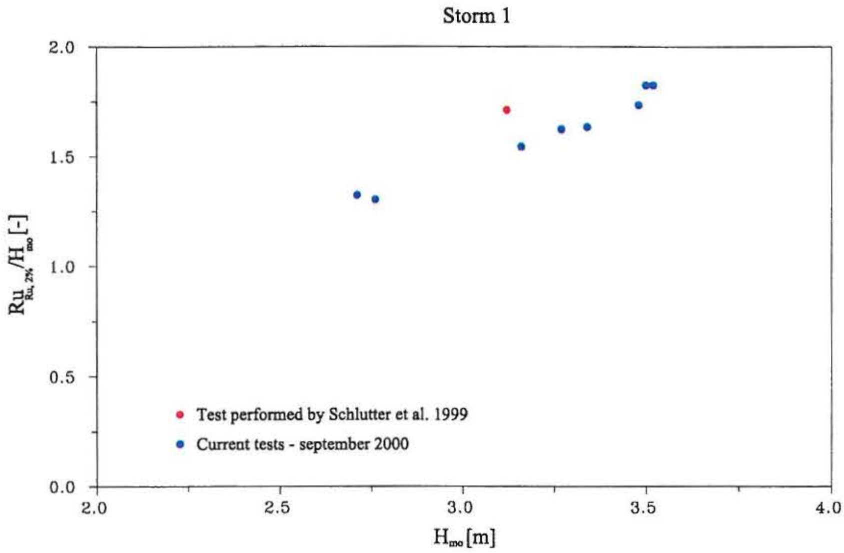



Figure 8: *Comparison of the relative run-up between current and former tests performed at AAU.*

About 10 % smaller run-up is obtained compared to the former tests. The same method of analysis has been carefully followed as well as the same software used. This difference is not significant and most likely due to small changes in the breakwater model or the simulated spectrum. Furthermore, the parameter 2% run-up is a sensitive parameter.

This storm event has a target waterlevel at 5.07 m. A relatively high level, where the difference between prototype and model is less significant.

## 2.3 Sensitivity related to permeability of the rubble mound slope

In the following the influence of "permeability" of the slope was investigated. Test 1 is performed under the same conditions as the originally breakwater. In test 2 the spaces between the units under the stepgauge is partly filled with smaller stones. During test 3 all the units are placed so practical no space between the units was present. The wave climate at Waverider 1 can be described with the following spectral values $H_{mo}$=2.35 m, $T_p$=8.00 sec. and $T_{01}$=6.15 sec.. The target waterlevel was 5.28 m. The tests were performed twice and all with the same stored wavegenerating signal.

| Test no. | $Ru_{ru,2\%}/H_{mo}$ [-] |
|---|---|
| 1 | 1.39 |
| 1 | 1.38 |
| 2 | 1.60 |
| 2 | 1.60 |
| 3 | 1.79 |
| 3 | 1.81 |

As expected an increase in run-up is observed. Clearly, run-up is very sensitive to the "permeability" of the slope. An increase of 30 % is observed from test 1 to test 3. Adjusting the run-up results depicted in figure 6 by increasing them with 30 % and figure 9 can be made.

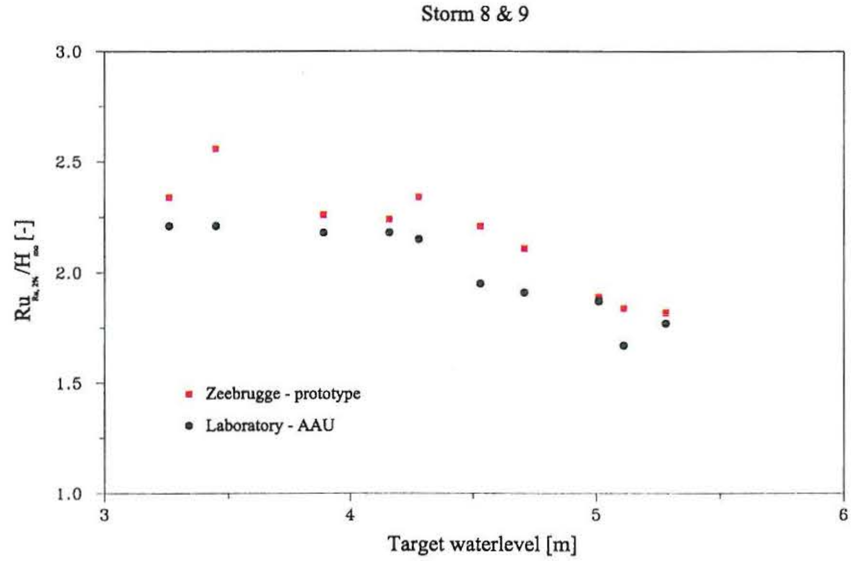



Figure 9: *The "adjusted" relative run-up measured in laboratory compared to prototype results.*

A good agreement between prototype data and "adjusted model" data is now observed.

## 2.4 Further analysis of wave run-up

In total 87 tests were performed during this subtask. This data are basis for the following graphs showing the relative run-up results plotted against the spectral width parameter and the Irribarren number.

The spectral width and Irribarren parameter are calculated on basis of the wave spectrum measured close to the breakwater (wavegauge Ze7) and not the position of Waverider 1. For calculation of the Irribarren number the wave parameters $H_{m0}$ and $T_{01}$ are used.

The results are seen in figure 10 and figure 11.

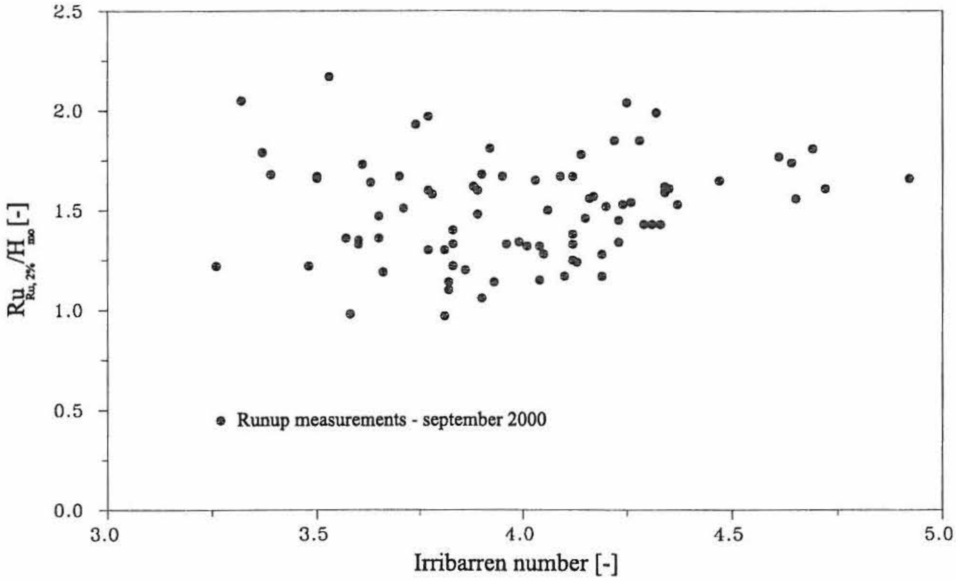



Figure 10: *The relative wave run-up versus the Irribarren number.*

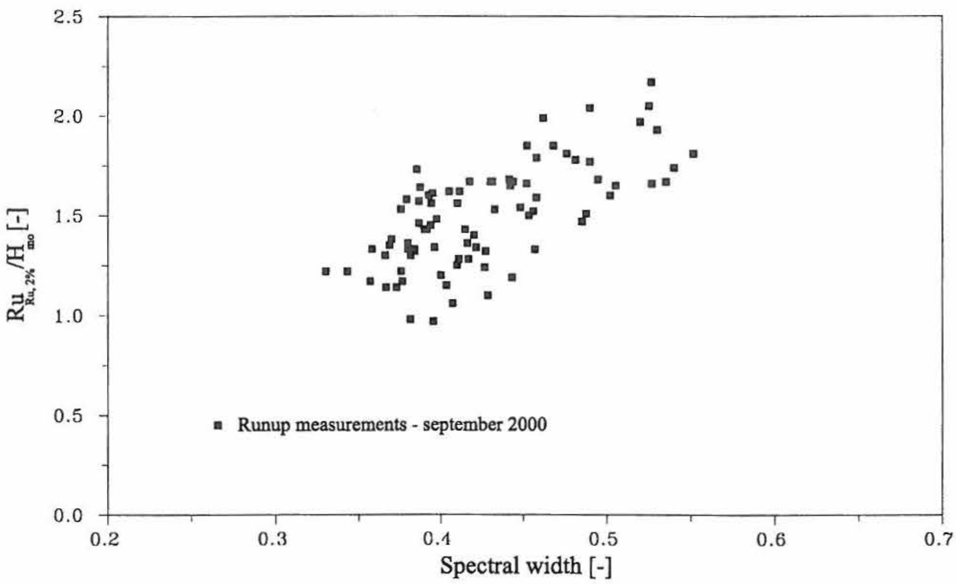



Figure 11: *The relative wave run-up versus the spectral width parameter.*

# 3 Run-up tests with a simulated current

A longshore current was simulated in the laboratory with the aim to investigate the effect on wave run-up. A pumping system were installed in the laboratory, see figure 12.


Figure 12: *A system of pumps generated the current in the laboratory.*

In total 10 test were performed. The wave direction of the waves and strength of the current were varied. The current is a mean averaged value and measured by two propeller. A realistic profile was made by directing the flow of water through some baskets filled with stones. A Jonswap spectrum with the parametres $H_{m0} = 3.0$ m and $T_P = 7$ sec. was used and the MWL was 3.0 m. In the following table the results are given and figure 13 shows the results from the test. Both $H_{mo}$ measured at waverider 1 and close to the model (wavegauge ze7) are given.

| Cur.[m/s] | Dir.[deg] | $H_{mo,w1}$[m] | $H_{mo,ze7}$[m] | $Ru_{ru,2\%}$[m] | $Ru_{ru,2\%}/H_{mo,wl}$[-] | $Ru_{ru,2\%}/H_{mo,ze7}$[-] |
|---|---|---|---|---|---|---|
| 1.0 | 0 | 2.90 | 3.38 | 4.73 | 1.63 | 1.40 |
| 1.0 | 0 | 2.98 | 3.42 | 4.68 | 1.57 | 1.37 |
| 1.0 | 15 | 3.24 | 2.95 | 4.31 | 1.33 | 1.46 |
| 1.0 | 15 | 3.34 | 3.20 | 4.74 | 1.42 | 1.48 |
| 0.5 | 15 | 2.90 | 2.63 | 3.44 | 1.19 | 1.31 |
| 0.5 | 15 | 2.90 | 2.54 | 3.46 | 1.19 | 1.36 |
| 0.5 | 0 | 2.92 | 2.61 | 3.44 | 1.18 | 1.32 |
| 0.5 | 0 | 2.97 | 2.62 | 3.48 | 1.17 | 1.33 |
| 0.0 | 0 | 2.95 | 3.58 | 4.30 | 1.46 | 1.20 |
| 0.0 | 0 | 2.96 | 3.55 | 4.44 | 1.50 | 1.25 |

It is observed that the relative run-up is affected by the current, see figure 13. If one concentrates on the relative run-up events close to the breakwater an increase in the relative run-up is seen. Also from the sparse data the angle of attack seems to have no significant effect.

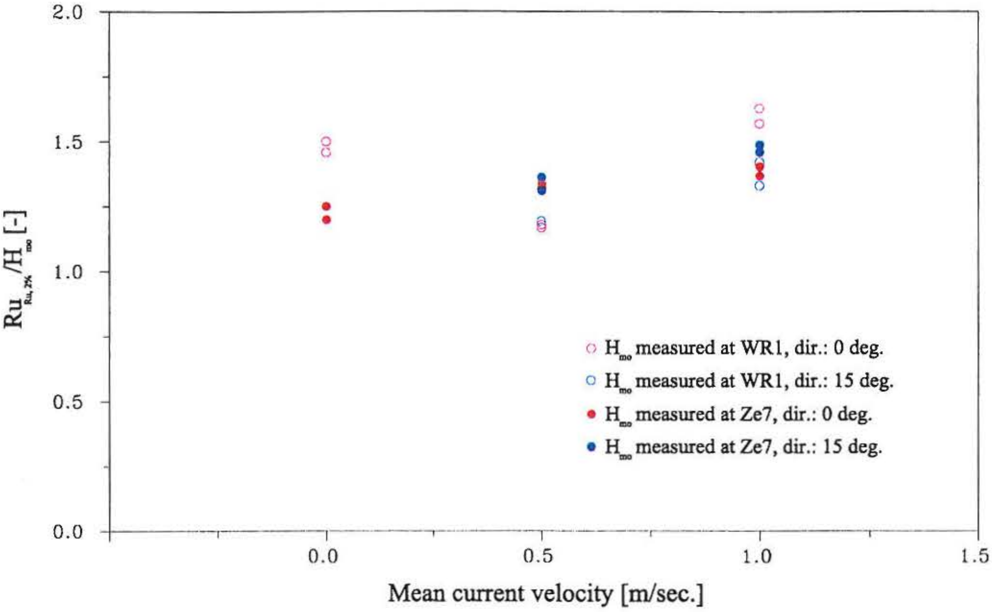



Figure 13: *Run-up results with a simulated current.*

The relative run-up of reference, i.e tests with no introduced current, were expected to be somewhat higher than 1.5. If figure 6 is observed with a waterlevel of 3 m a value of 1.7 seems likely. A reason for this could be that some wave breaking was observed. The target waterlevel was slightly lower than compared with the storm events.

/1/ Frigaard, P., et al., October 1999. *"Bremen Workshop, Run-up"*. OPTICREST, MAS3-CT97-0116.

/2/ Frigaard, P., Schlutter, F., June 1999. *"Laboratory Investigations - Methodology."*. OPTICREST Research report, Aalborg University, MAS3-CT97-0116, Final version.

# 4 Results of run-up and run-down for the simulated storms

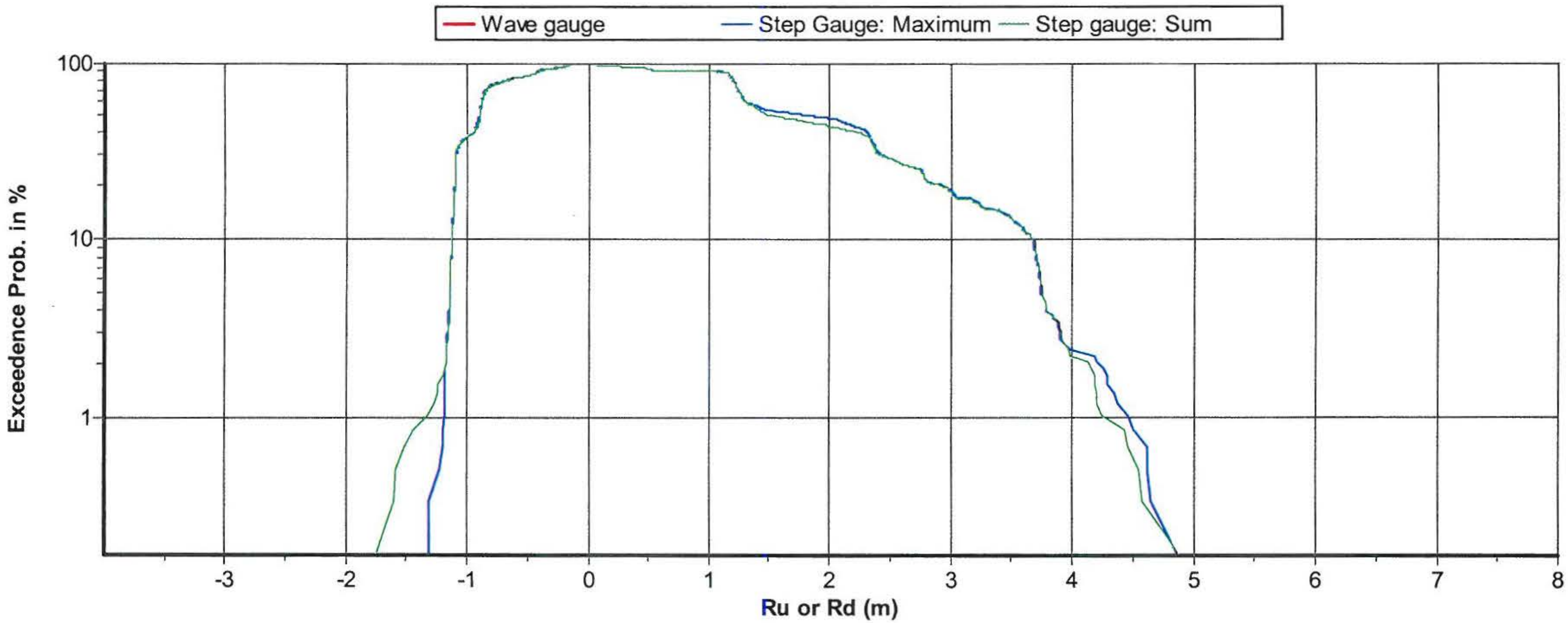
| Storm no./time | TWL [m] | $H_{mo}$ [m] | $Ru_{ru,2\%}$[m] | $Ru_{ru,5\%}$ [m] | $Ru_{ru,10\%}$ [m] | $Ru_{ru,50\%}$ [m] |
|---|---|---|---|---|---|---|
| 8/9h30-10h30 | 3.45 | 2.31 | 4.13 | 3.75 | 3.68 | 1.59 |
| 8/10h30-11h30 | 4.53 | 2.75 | 4.14 | 3.75 | 3.52 | 2.53 |
| 8/11h30-13h30 | 5.28 | 2.99 | 4.24 | 3.78 | 3.39 | 2.50 |
| 8/13h30-14h30 | 5.01 | 2.90 | 4.15 | 3.76 | 3.51 | 2.08 |
| 8/14h30-15h30 | 4.28 | 2.49 | 3.93 | 3.69 | 3.02 | 2.04 |
| 9/21h45-22h45 | 3.26 | 2.49 | 4.11 | 3.92 | 3.54 | 1.46 |
| 9/22h45-23h45 | 4.16 | 2.60 | 4.23 | 3.95 | 3.28 | 2.21 |
| 9/23h45-01h45 | 5.11 | 2.59 | 3.34 | 3.17 | 2.98 | 1.86 |
| 9/01h45-02h45 | 4.71 | 2.54 | 3.53 | 3.34 | 3.06 | 2.11 |
| 9/02h45-03h45 | 3.89 | 2.14 | 3.49 | 3.37 | 3.26 | 1.89 |

| Storm no./time | TWL [m] | $H_{mo}$ [m] | $Ru_{rd,2\%}$[m] | $Ru_{rd,5\%}$ [m] | $Ru_{rd,10\%}$ [m] | $Ru_{rd,50\%}$ [m] |
|---|---|---|---|---|---|---|
| 8/9h30-10h30 | 3.45 | 2.31 | 1.18 | 1.16 | 1.13 | 0.91 |
| 8/10h30-11h30 | 4.53 | 2.75 | 2.06 | 1.92 | 1.74 | 1.35 |
| 8/11h30-13h30 | 5.28 | 2.99 | 2.43 | 2.14 | 2.06 | 1.28 |
| 8/13h30-14h30 | 5.01 | 2.90 | 2.47 | 2.42 | 2.23 | 1.82 |
| 8/14h30-15h30 | 4.28 | 2.49 | 2.22 | 2.04 | 1.86 | 1.28 |
| 9/21h45-22h45 | 3.26 | 2.49 | 2.31 | 2.19 | 2.01 | 1.14 |
| 9/22h45-23h45 | 4.16 | 2.60 | 1.82 | 1.75 | 1.66 | 1.06 |
| 9/23h45-01h45 | 5.11 | 2.59 | 2.21 | 2.07 | 2.02 | 1.51 |
| 9/01h45-02h45 | 4.71 | 2.54 | 1.99 | 1.88 | 1.80 | 1.39 |
| 9/02h45-03h45 | 3.89 | 2.14 | 1.57 | 1.54 | 1.37 | 0.74 |

# Run-up and run-down of short-crested waves

## Input

| | | | |
|---|---|---|---|
| *Data file* | *Z101a.006* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.43* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *7.2* | *Number of waves* | *589* |





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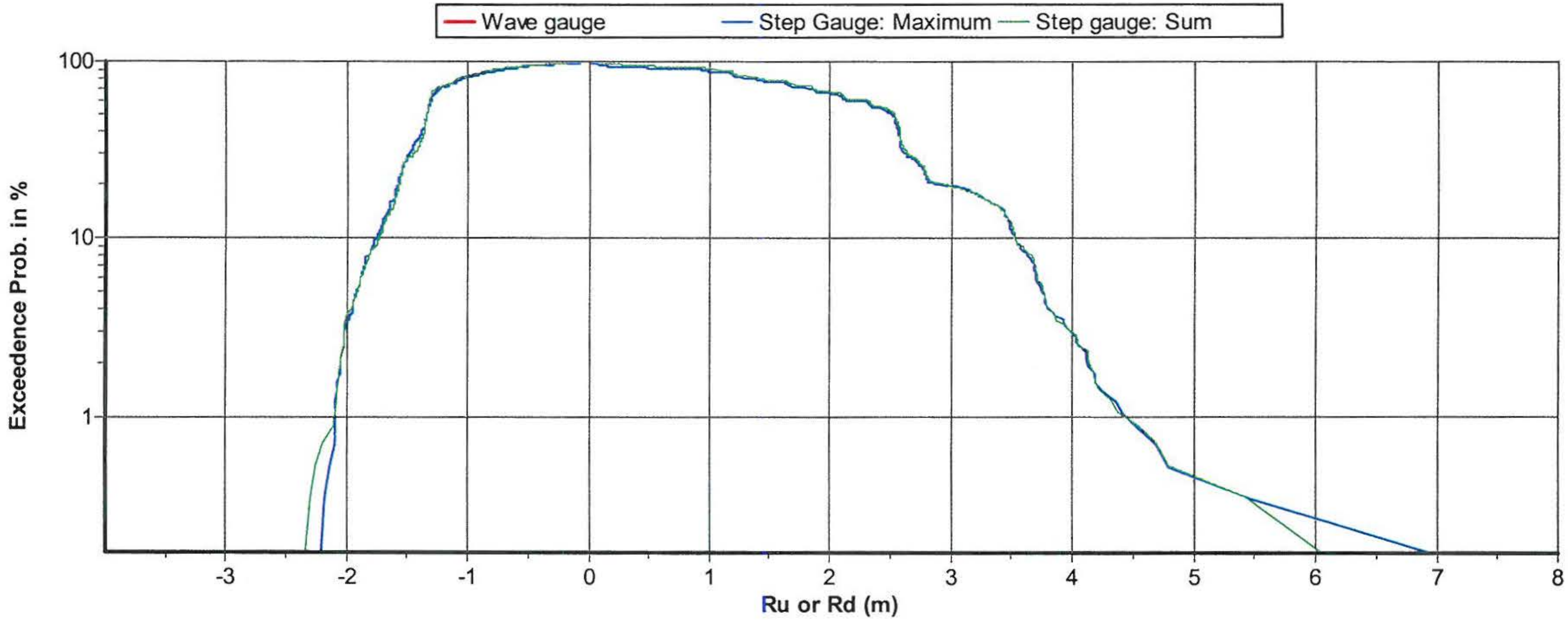
| *Date* | *11-10-00* |
| *Remarks* | |

# Run-up and run-down of short-crested waves

## Input

| | | | |
|---|---|---|---|
| *Data file* | *Z101b.013* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.76* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *7.2* | *Number of waves* | *552* |





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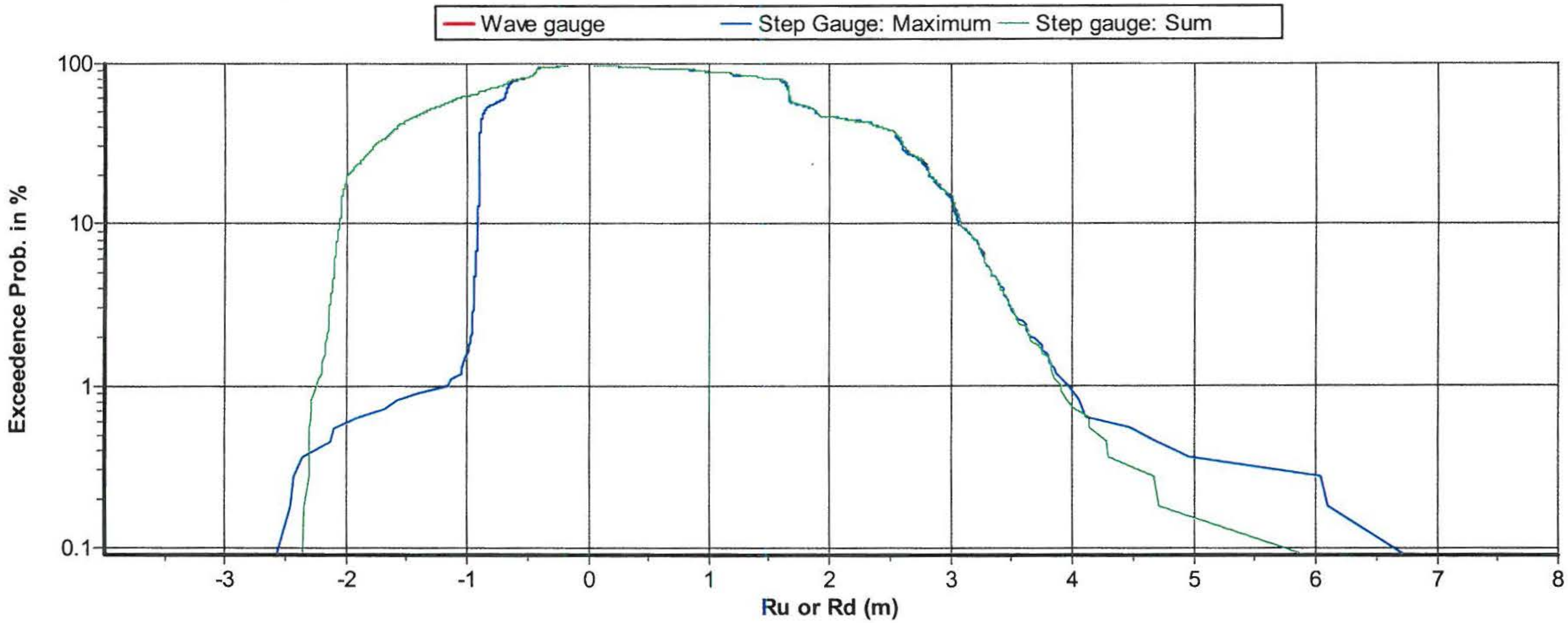
# Run-up and run-down of short-crested waves

| Input | | | | |
|---|---|---|---|---|
| | *Data file* | *Z101c.007* | *Mean incident angle (deg)* | *0* |
| | *Incident Hmo (m)* | *3.12* | *Energy spreading angle (deg)* | *0* |
| | *Peak wave period (s)* | *8.0* | *Number of waves* | *1089* |

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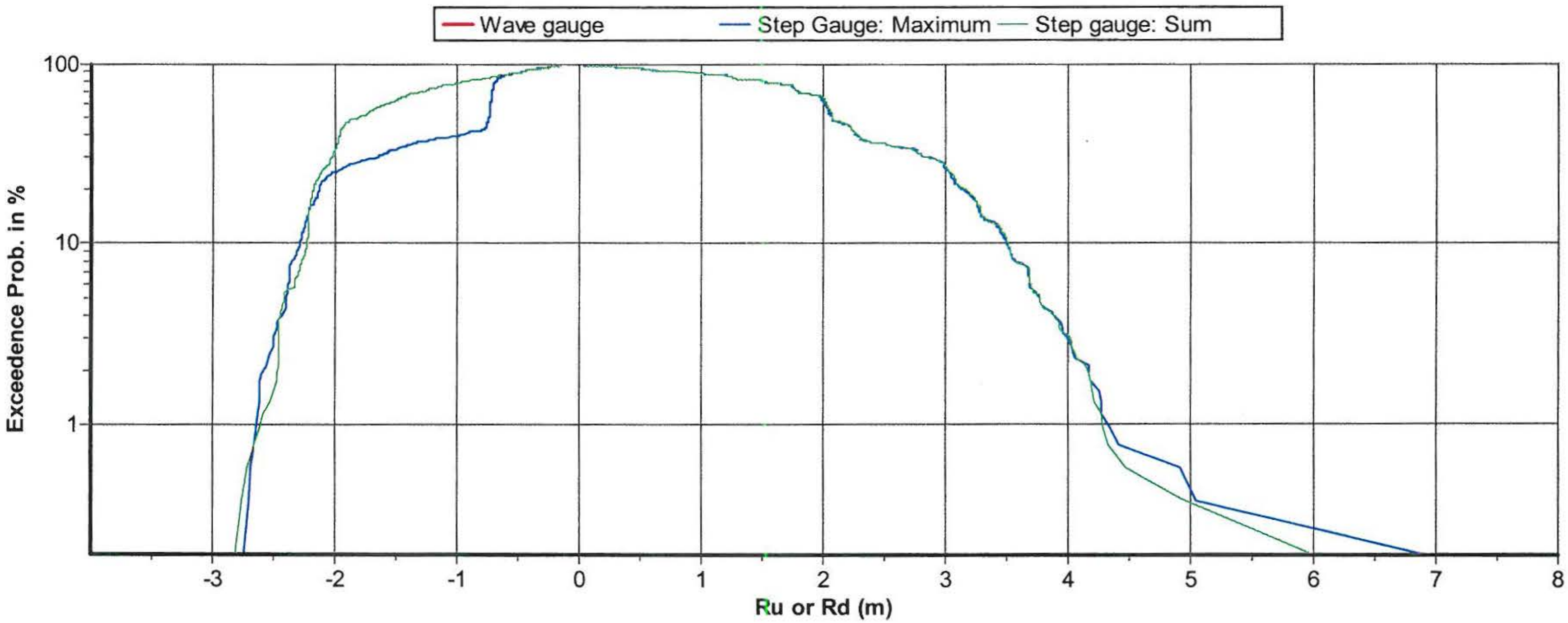
# Run-up and run-down of short-crested waves

## Input

| | | | |
|---|---|---|---|
| *Data file* | *Z101d.012* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.88* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *7.2* | *Number of waves* | *523* |





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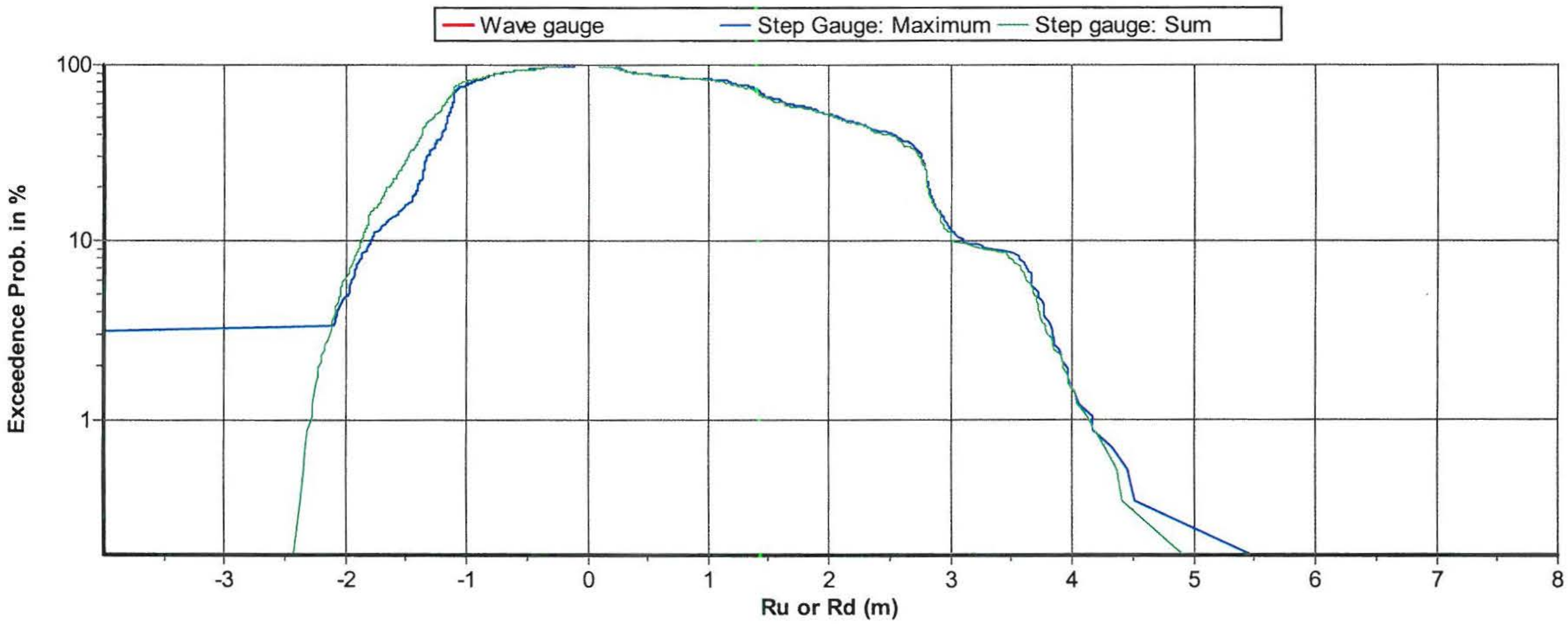
| *Remarks* | |

# Run-up and run-down of short-crested waves

## Input

| | | | |
|---|---|---|---|
| *Data file* | *Z101e.004* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.38* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *7.2* | *Number of waves* | *564* |





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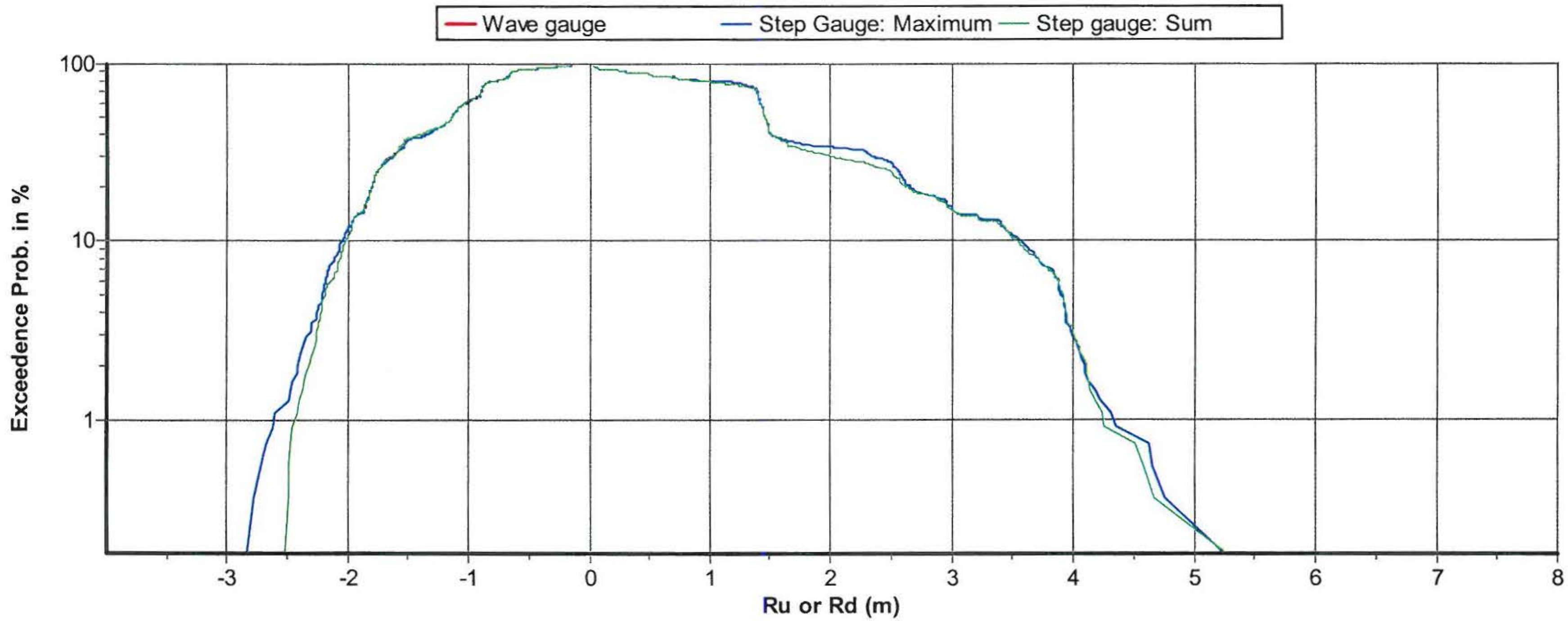
| *Remarks* | |

# Run-up and run-down of short-crested waves

| Input | | | | |
|---|---|---|---|---|
| | *Data file* | *Z102a.007* | *Mean incident angle (deg)* | *0* |
| | *Incident Hmo (m)* | *2.42* | *Energy spreading angle (deg)* | *0* |
| | *Peak wave period (s)* | *7.2* | *Number of waves* | *546* |





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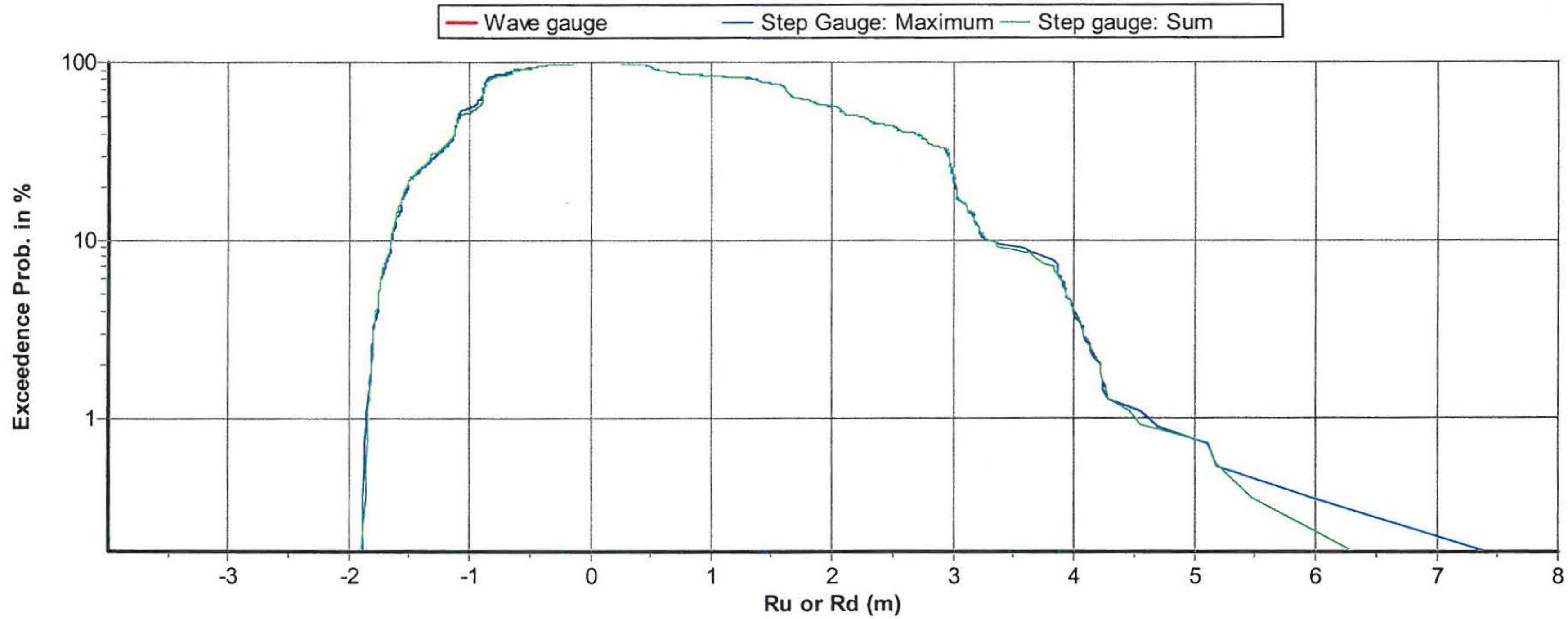
| *Date* | *11-10-00* |
| *Remarks* | |

# Run-up and run-down of short-crested waves

Input

| | | | |
|---|---|---|---|
| *Data file* | *Z102b.008* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.52* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *7.2* | *Number of waves* | *546* |





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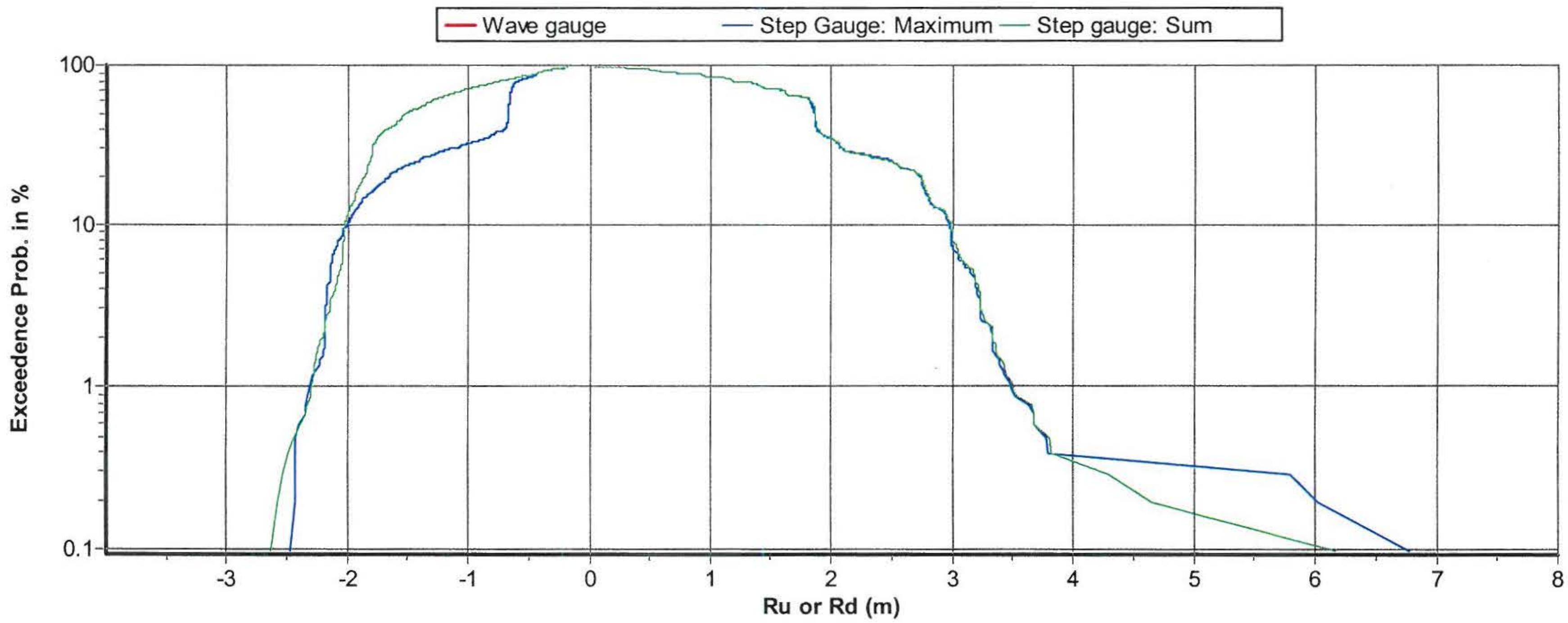
| *Date* | *11-10-00* |
| *Remarks* | |

# Run-up and run-down of short-crested waves

| Input | | | | |
|---|---|---|---|---|
| | Data file | Z102c.005 | Mean incident angle (deg) | 0 |
| | Incident Hmo (m) | 2.61 | Energy spreading angle (deg) | 0 |
| | Peak wave period (s) | 8.9 | Number of waves | 1039 |





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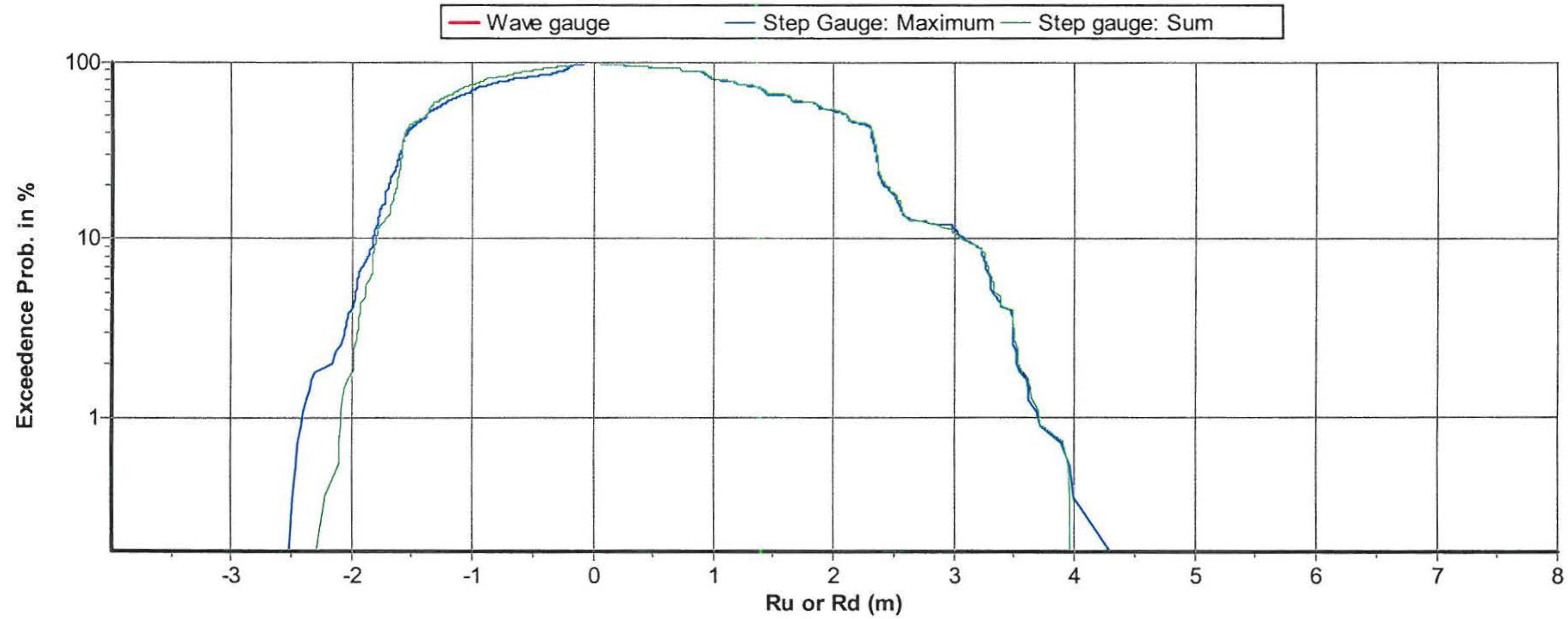
| | |
|---|---|
| Project title | OPTICREST |
| Drawn by | |
| Date | 11-10-00 |
| Remarks | |

# Run-up and run-down of short-crested waves

Input

| | | | |
|---|---|---|---|
| *Data file* | *Z102d.008* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.40* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *8.9* | *Number of waves* | *550* |





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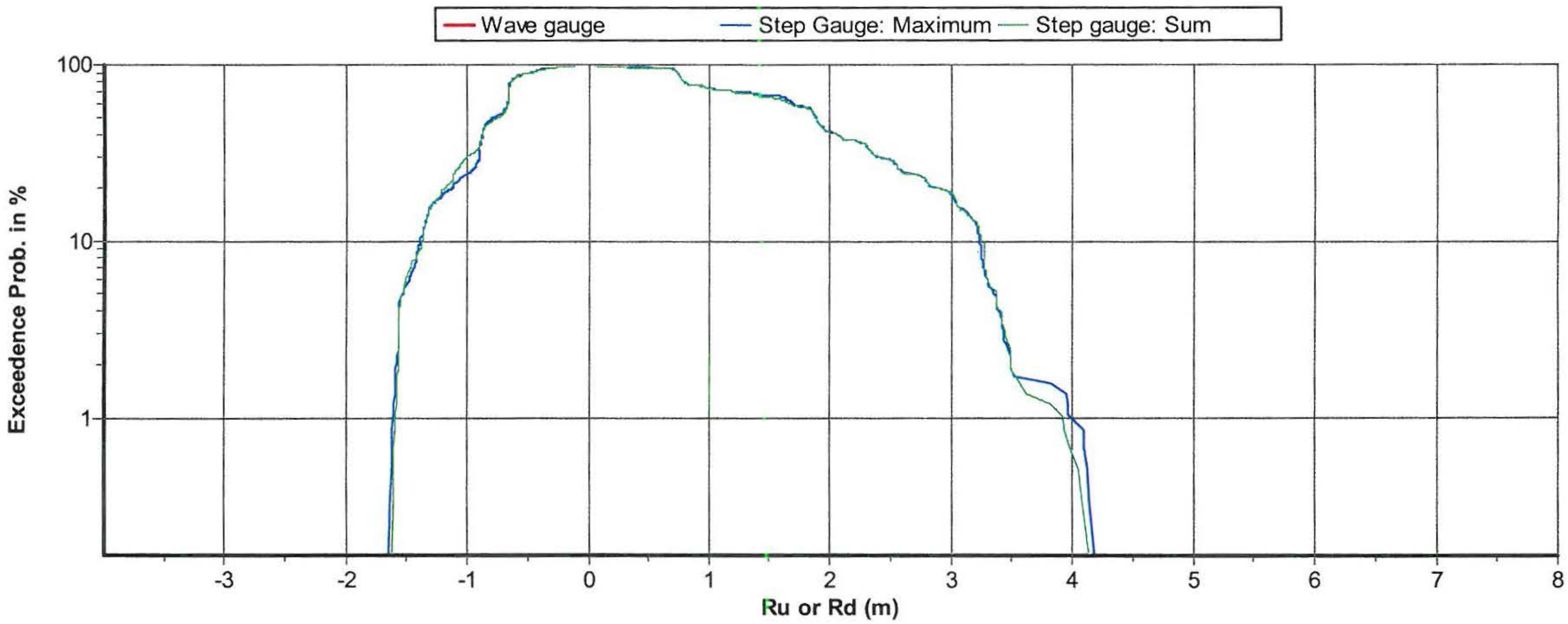
| | |
|---|---|
| *Project title* | *OPTICREST* |
| *Drawn by* | |
| *Date* | *11-10-00* |
| *Remarks* | |

# Run-up and run-down of short-crested waves

## Input

| | | | |
|---|---|---|---|
| *Data file* | *Z102e.010* | *Mean incident angle (deg)* | *0* |
| *Incident Hmo (m)* | *2.08* | *Energy spreading angle (deg)* | *0* |
| *Peak wave period (s)* | *8.0* | *Number of waves* | *578* |





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| | |
|---|---|
| *Project title* | *OPTICREST* |
| *Drawn by* | |
| *Date* | *11-10-00* |
| *Remarks* | |